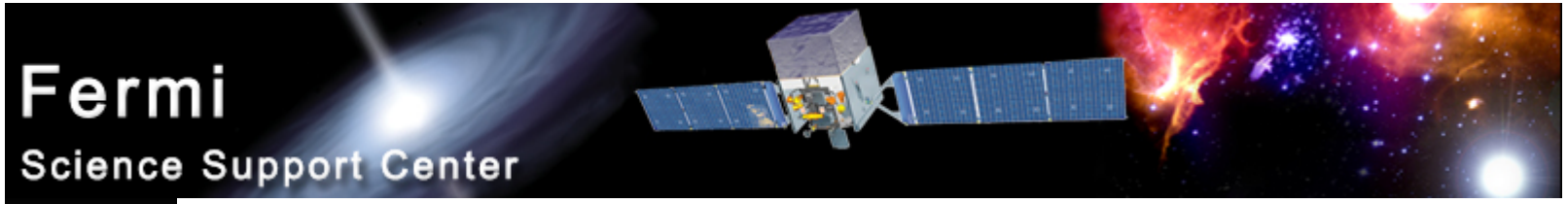
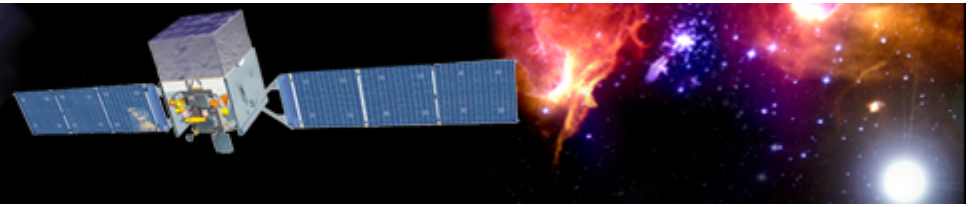
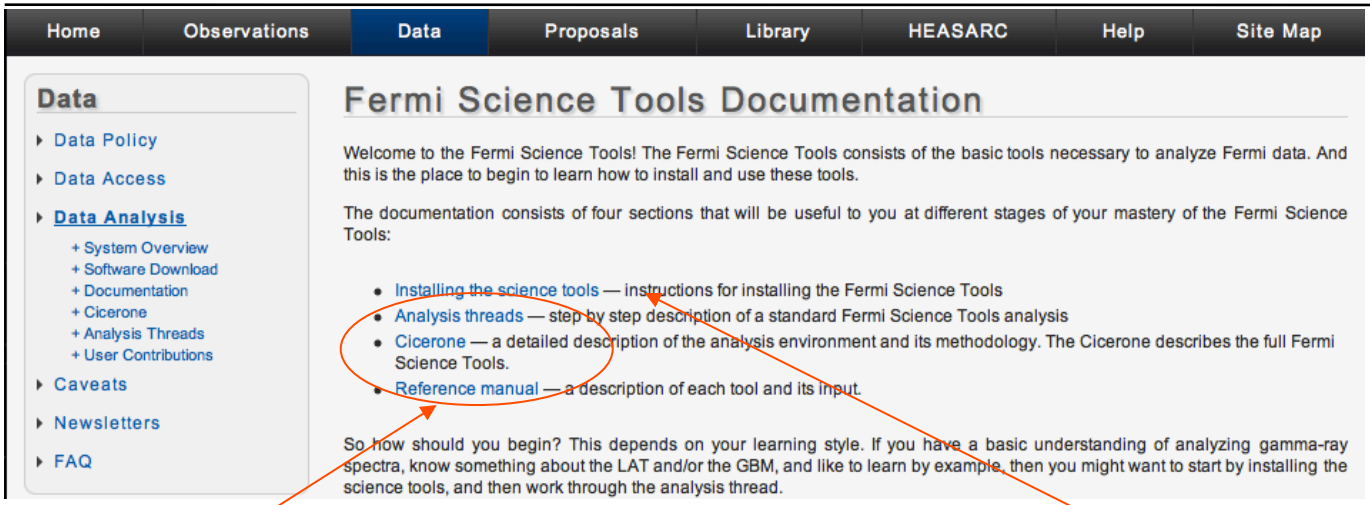



# FSSC Science Tools

# Data Retrieval, Selection and Exploration



# Where do we start from?

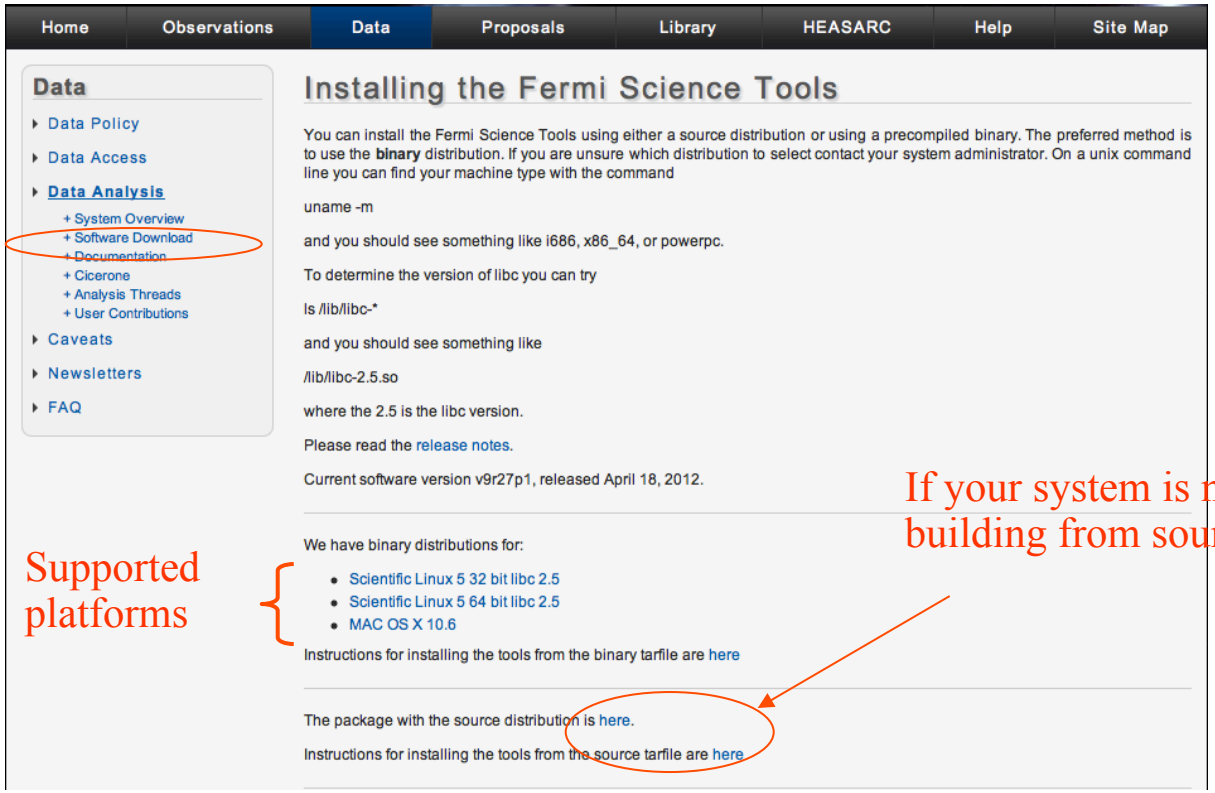


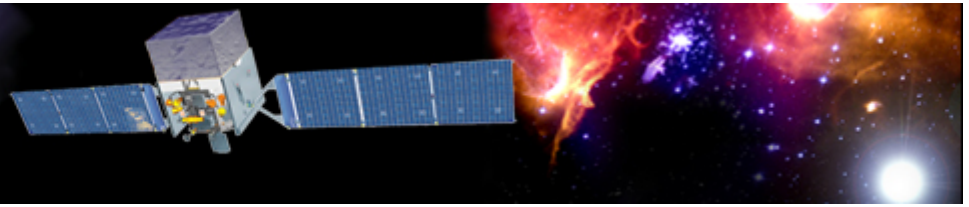

Multiple levels of Documentation

You should have already gone through this step

- Cicerone
  - General information on the satellite and instruments
  - Describes instrumentation and data acquisition
  - Explains analysis methods
- Analysis threads (cook book examples)
  - Follow the analysis chain step-by-step
- Individual tool descriptions (like fhelp)
  - Explains individual parameters in detail

# Downloading the software





# Science Analysis Threads

Home | Observations | Data | Proposals | Library | HEASARC | Help | Site Map

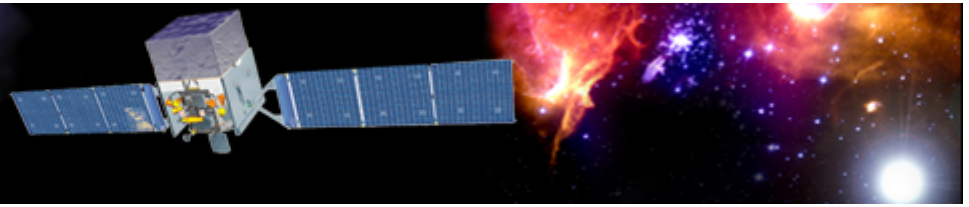
**Data**

- Data Policy
- Data Access
- **Data Analysis**
  - + System Overview
  - + Software Download
  - + Documentation
  - + Cicerone
  - + Analysis Threads
  - + User Contributions
- Caveats
- Newsletters
- FAQ

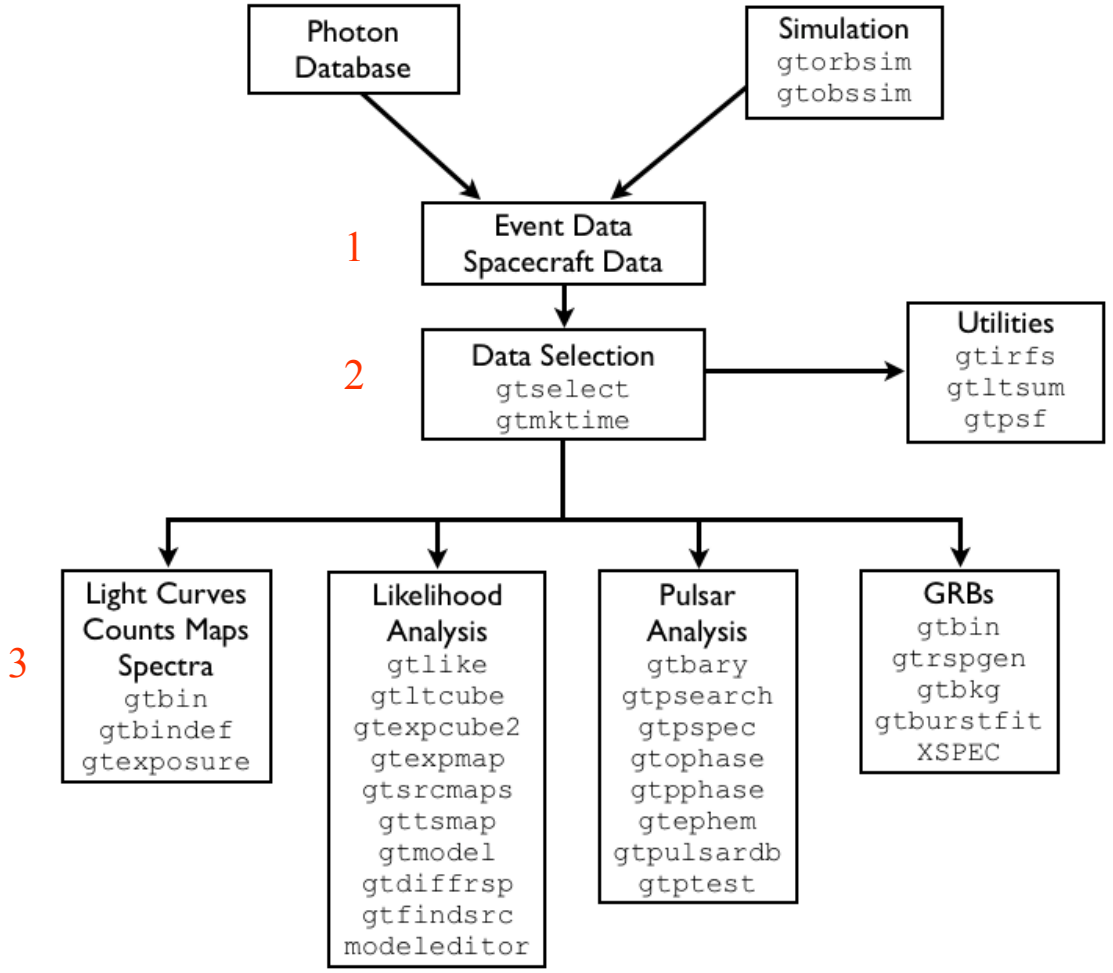
## Analysis Threads

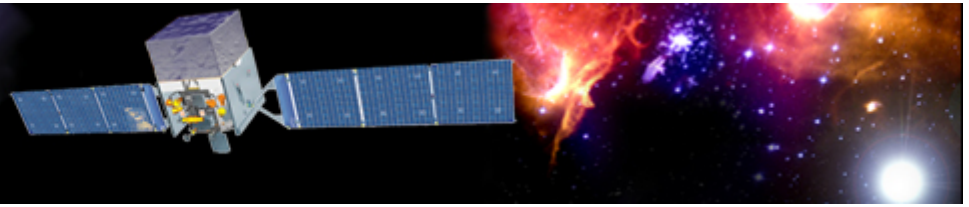
NOTE: These threads have been updated to account for changes in the LAT Pass 7 data. If you need information on Pass 6 data analysis, look here.

- Overview
- Data Selection
  - Extract LAT Data
  - Data Preparation
  - Explore LAT Data
  - Explore LAT Data (for Burst)
- Source Analysis
  - Likelihood Tutorial
  - Binned Likelihood Tutorial
  - Likelihood Analysis from Python
  - Extended Source Analysis (Binned Analysis from Python)
  - LAT Aperture Photometry Analysis
  - Source Identification
  - Pulsar Gating Tutorial
  - Upper Limit Calculation (LATAnalysisScripts)
- GRB Analysis
  - LAT GRB Analysis
  - GBM GRB Analysis
  - Combined LAT and GBM analysis
- Pulsar Analysis
  - Pulsar Analysis Overview
  - Ephemeris Data File
  - Pulse Phase Calculation
  - Periodicity Test
  - Ephemeris Computation Utility
  - Period Search
  - Pulsation Search
  - Binary Orbital Phase Calculation
  - Arrival Time Correction
- ObsSim
  - Observation Simulation Tutorial
  - Orbsim Tutorial
  - Other Sources for gtobssim



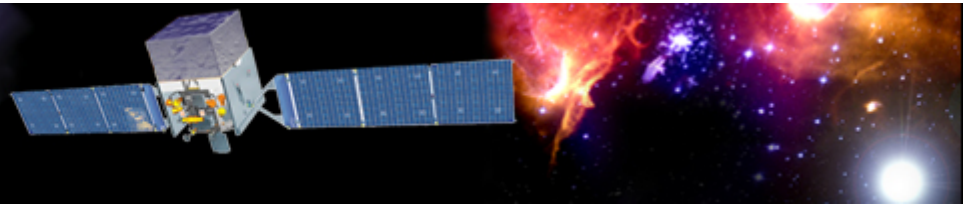
# Science Analysis Structure





# Science Tools

- Individual tools
  - Allows for divergent analysis without task repetition
  - Scriptable into more complex analysis chains
- Standard file types
  - FITS data i/o
  - IRAF style param files
  - XML source models
  - Text-based supporting files
- Standard toolsets for astronomy
  - fv, ds9, Xspec



# Parameter Files

Contain parameter defaults or last used values

```
#
# $Header: /nfs/slac/g/glast/ground/cvs/dataSubselector/pfiles/gtselect.par,v 1.21 2010/07/23 15:53:32 jchiang Exp $
#
infile,f,a,"",,,"Input FT1 file"
outfile,f,a,"",,,"Output FT1 file"
ra,r,a,INDEF,0,360,RA for new search center (degrees)
dec,r,a,INDEF,-90,90,Dec for new search center (degrees)
rad,r,a,INDEF,0,180,radius of new search region (degrees)
tmin,r,a,INDEF,0,,start time (MET in s)
tmax,r,a,INDEF,0,,end time (MET in s)
emin,r,a,100,0,,lower energy limit (MeV)
emax,r,a,300000,0,,upper energy limit (MeV)
zmax,r,a,180,0,180,maximum zenith angle value (degrees)
evclsmin,i,h,INDEF,0,1000,"Minimum event class ID"
evclsmax,i,h,INDEF,0,1000,"Maximum event class ID"
evclass,i,h,2,0,31,"Event class selection (e.g. 0=Transient, 2=Source)"
convtype,i,h,-1,-1,1,"Conversion type (-1=both, 0=Front, 1=Back)"
phasemin,r,h,0,0,1,minimum pulse phase
phasemax,r,h,1,0,1,maximum pulse phase

evtable,s,h,"EVENTS",,,"Event data extension"

chatter,i,h,2,0,4,Output verbosity
clobber,        b, h, yes, , , "Overwrite existing output files"
debug,          b, h, no, , , "Activate debugging mode"
gui,            b, h, no, , , "GUI mode activated"
mode,           s, h, "ql",_, , "Mode of automatic parameters"
```

Tool-specific parameters

General

Structure of parameters:
- name
- type (boolean, string, real, integer, filename)
- mode: a = prompted; h = hidden
- default value
- minimum
- maximum
- prompt

Useful suggestions:
1) fhelp gtselect
2) plist gtselect
3) punlearn gtselect
4) pset gtselect emin=200
5) gtselect emin=200 chatter=4
6) mode=h

# Data Access: Downloads

General LAT Data Query :

Allows retrieval of data for a specified region

- Default values correspond to suggested data
- Selections for most analysis types

Weekly files :

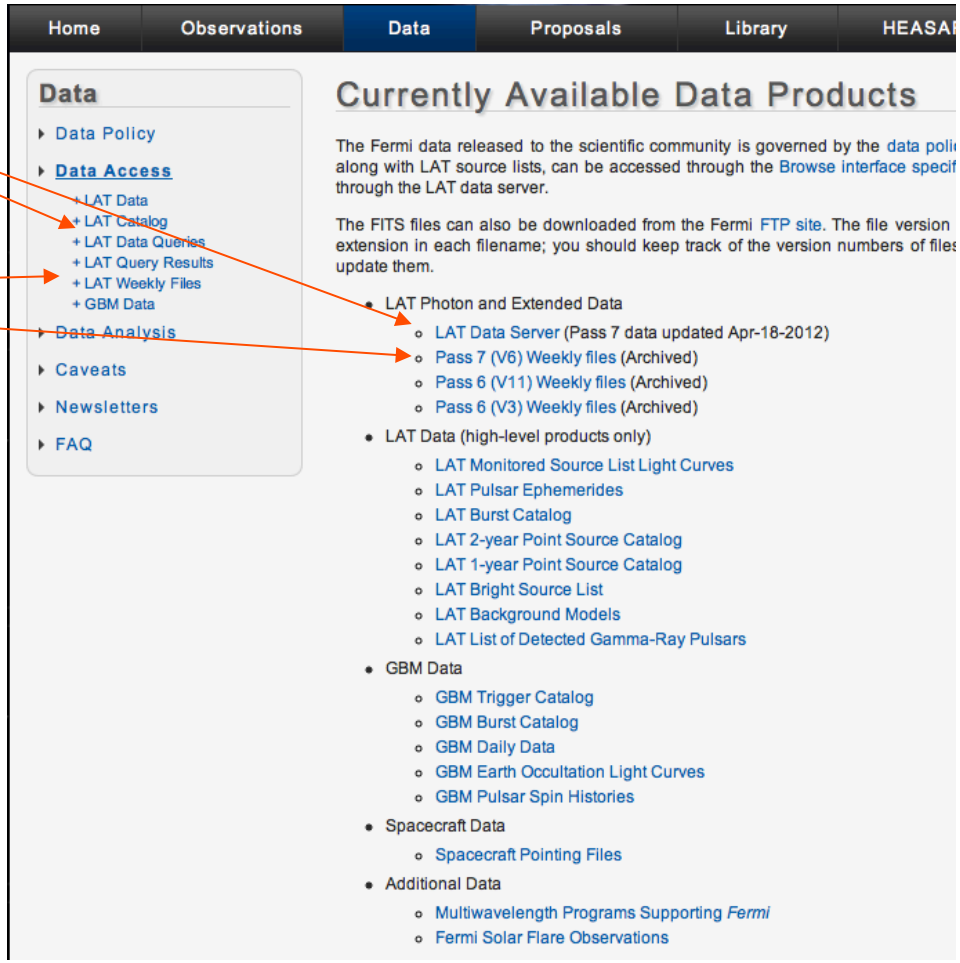
It is a faster method for whole sky analysis

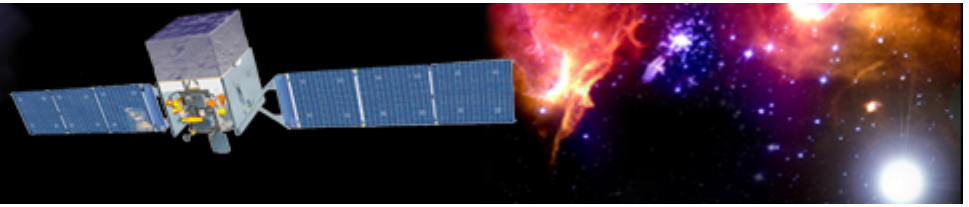
- Weekly event/spacecraft files
- Can be retrieved automatically using wget:

- wget ftp://legacy.gsfc.nasa.gov/fermi/data/lat/weekly/…/
  (replace … with "spacecraft" or "photon")

- you'll get an "index.html" file with the list of fits file available for either the spacecraft or event files.

- wget the interested files:
  wget lat_spacecraft_weekly_wXXX_pYYY_vZZZ.fits





# Data Access: File types

- Events File (2 types)
  - **Photon** files contain information for standard science analysis, corresponding to these event classes:

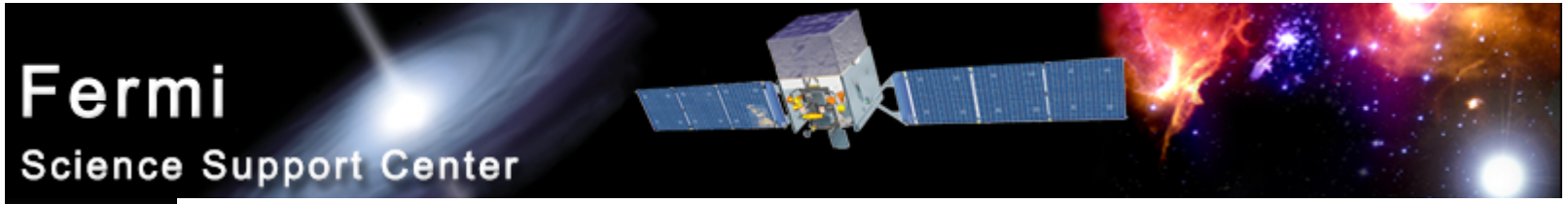
| *Class (pass7)* | *EVENT_CLASS* | *Class (pass6)* | *old EVENT_CLASS cut* |
|---|---|---|---|
| *Source* | *2* | *Diffuse* | *EVENT_CLASS >= 3* |
| *Clean* | *3* | *DataClean* | *EVENT_CLASS >= 4* |
| *UltraClean* | *4* | *None* | *None* |

The correlation between the classification in Pass 6 and 7 is tentative.
The pass 6 cut are discontinued for any data reprocessed after August 1, 2011.

  - **Extended** files contain additional information about each event that is used for specialized analysis (transient sources like GRBs)

| *Class (pass7)* | *EVENT_CLASS* | *Class (pass6)* | *old EVENT_CLASS cut* |
|---|---|---|---|
| *Transient* | *0* | *Transient* | *EVENT_CLASS >= 1* |

- Spacecraft File
  - Spacecraft Orientation and orbit position information
    - where Fermi is and where Fermi is pointed
  - One entry every 30 seconds




# Data Access: Data Server

HOME | OBSERVATIONS | DATA | PROPOSALS | LIBRARY | HEASARC | HELP | SITE MAP

+ FSSC Home

**Data**

Data Policy

Data Access

+ LAT Data
+ LAT Catalog
+ LAT Data Queries
+ LAT Query Results
+ LAT Weekly Files
+ GBM Data

Data Analysis

Caveats

Newsletter

FAQ

**LAT Photon, Event, and Spacecraft Data Query**

**April 19 2012**: The data server is now loaded with Pass7 photon data. This data has the updated diffuse response columns. We do not recommend mixing the data before April 18 with the current data if you are doing unbinned analysis. Analysis using Binned Likelihood is unaffected.

**NOTE:** For queries encompassing the whole sky (or close to it), please use the pre-generated Weekly All-Sky Files available through HEASARC Browse.

**NOTE:** Additional selections must be applied to data downloaded from the data server prior to use in a data analysis. See **recommended data selections** and **LAT caveats** for more details.

The photon database currently holds 189900846 photons, collected between 2008-08-04T15:43:37 UTC and 2012-05-21T14:10:26 UTC (Mission Elapsed Time (MET) 239557417 to 359302226 seconds).

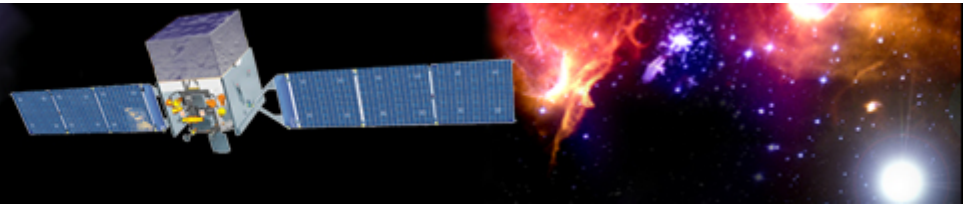
The event database currently holds 1349522855 events, collected between 2012-04-18T09:42:58 UTC and 2012-05-21T14:10:26 UTC (Mission Elapsed Time (MET) 356434978 to 359302226 seconds).

Use xTime to convert between MET and other time systems.

Start Search | Reset

| | |
|---|---|
| **Object name or coordinates:** | NED/Simbad/GRB name |
| **Coordinate system:** | J2000 |
| **Search radius (degrees):** | in degrees |
| **Observation dates:** | Gregorian, MET, MJD. Can use "START" and "END" |
| **Time system:** | Gregorian |
| **Energy range (MeV):** | 100 MeV to 300,000 MeV |
| **LAT data type:** | Photon / Extended / None |
| **Spacecraft data:** | ☑ |

Coordinates, energy, and dates are comma-separated



# Data Access: Data Server - Results

Start Search | Reset

| | |
|---|---|
| **Object name or coordinates:** | 193.98, -5.82 |
| **Coordinate system:** | J2000 |
| **Search radius (degrees):** | 20 |
| **Observation dates:** | START, 255398400 |
| **Time system:** | MET |
| **Energy range (MeV):** | 100, 100000 |
| **LAT data type:** | Photon |
| **Spacecraft data:** | ☑ |

Search was for 3C 279

**Results for query L1203211445197365007F88**

Your search criteria were:

| | |
|---|---|
| Equatorial coordinates (degrees) | (193.98,-5.82) |
| Time range (MET) | (239557417,255398400) |
| Time range (Gregorian) | (2008-08-04 15:43:37,2009-02-04 00:00:00) |
| Energy range (MeV) | (100,100000) |
| Search radius (degrees) | 20 |

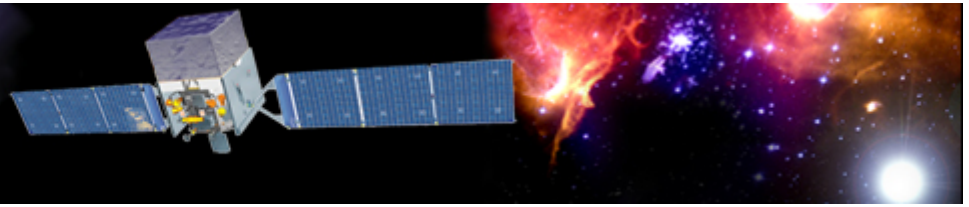
Save this information for future reference

The state of your query is 2 (Query complete)

| Server | Position in Queue | Estimated Time Remaining (sec) |
|---|---|---|
| Photon Server | Query complete | N/A |
| Spacecraft Server | Query complete | N/A |

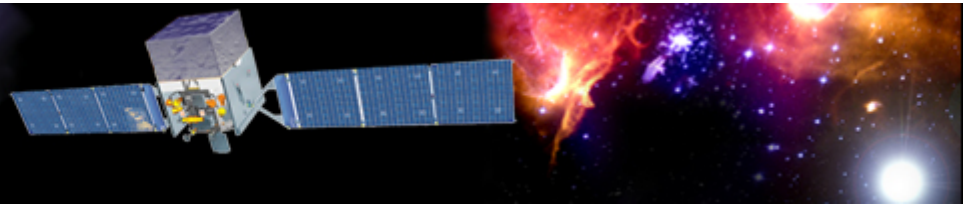
| Filename | Number of Entries | Size (MB) | Status |
|---|---|---|---|
| L1203211445197365007F88_PH00.fits | 183137 | 16.48 | Available |
| L1203211445197365007F88_SC00.fits | 445088 | 62.85 | Available |

For long exposures and/or large extraction area, there will be 2 or more photon files (PH00, PH01, …)



# Preparing your data

- Combine photon files if necessary
  - for tools like gtselect use @filelist.txt syntax where filelist.txt is a listing of all photon files to be included, one per line (ls *_PH* > filelist.txt)
- Prior to beginning an analysis you must:
  - Select the event class (default is 2=Source) and the conversion type (if needed)
  - Decide how you intend to exclude time intervals where the bright Earth limb comes close to the edge of your region of interest



# Data Selection

- Event-specific cuts can be made with **gtselect**
  - Time range, energy range, position, ROI radius, zenith angle

```
prompt> gtselect evclass=2
Input FT1 file[] L1203211445197365007F88_PH00.fits
Output FT1 file[] 3C279_region_filtered.fits
RA for new search center (degrees) (0:360) [0] 193.98
Dec for new search center (degrees) (-90:90) [0] -5.82
radius of new search region (degrees) (0:180) [180] 20
start time (MET in s) (0:) [0] 239557417
end time (MET in s) (0:) [0] 255398400
lower energy limit (MeV) (0:) [30] 100
upper energy limit (MeV) (0:) [300000] 100000
maximum zenith angle value (degrees) (0:180) [180] 100
```

Hidden parameter defined on the command line

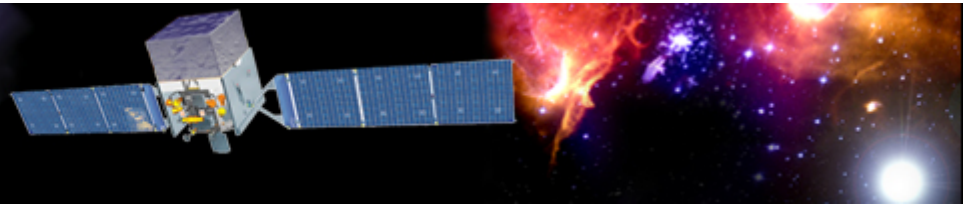
Or @filelist.txt

Parameter values can be read from the header keywords by inputting INDEF

- Temporal cuts using spacecraft file keywords are made with **gtmktime** (modifies GTIs in event file)
  - This MUST be applied EVERY TIME there is a new cut with gtselect

```
prompt> gtmktime
Spacecraft data file[] spacecraft.fits
Filter expression[] DATA_QUAL==1 && LAT_CONFIG==1 && ABS(ROCK_ANGLE)<52
Apply ROI-based zenith angle cut[yes]
Event data file[] 3C279_region_filtered.fits
Output event file name[] 3C279_region_filtered_gti.fits
```

Applies zenith angle cut from gtselect
Use "no" for very large extraction regions

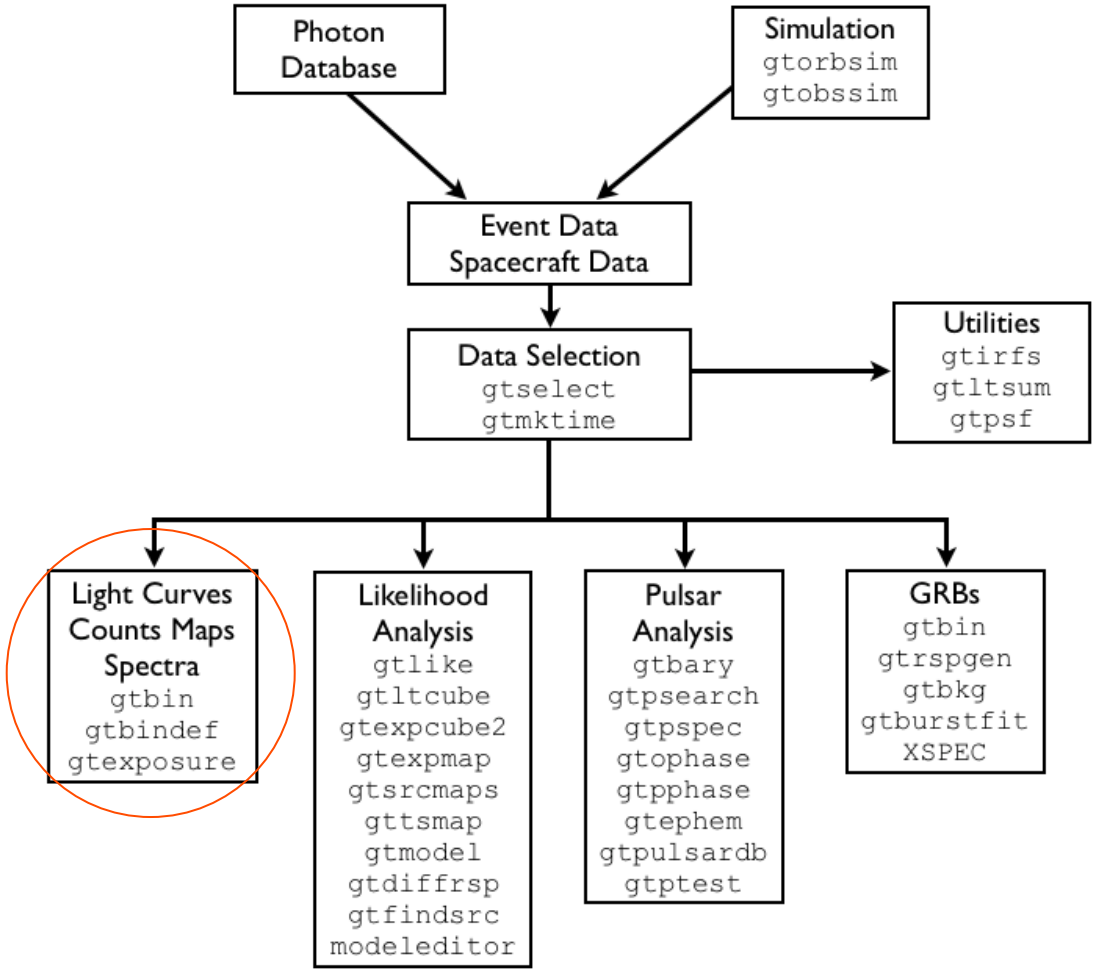


# Data Selection

- Different cuts should be used for different types of data analysis
  - Point Source analysis
    - For hard spectrum sources, localization analysis may benefit from a higher minimum energy cut due to energy-dependent PSF
  - Pulsar Timing analysis
    - Requires that spacecraft file span a greater time range than event file
    - Data server automatically pads the spacecraft file, unless you use START or END time keys
  - GRB analysis (~ few hundred seconds)
    - Typically uses "Transient" class photons (evclass=0)
- The current set of cuts can be reviewed using **gtvcut**
- Recommended cuts are documented at:

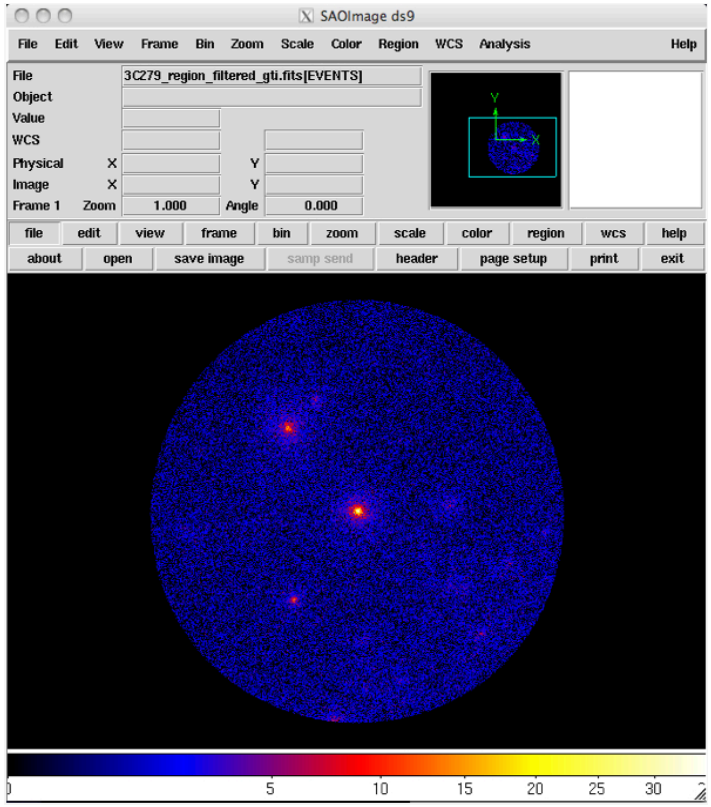
http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_Data_Exploration/Data_preparation.html

# Science Analysis Structure

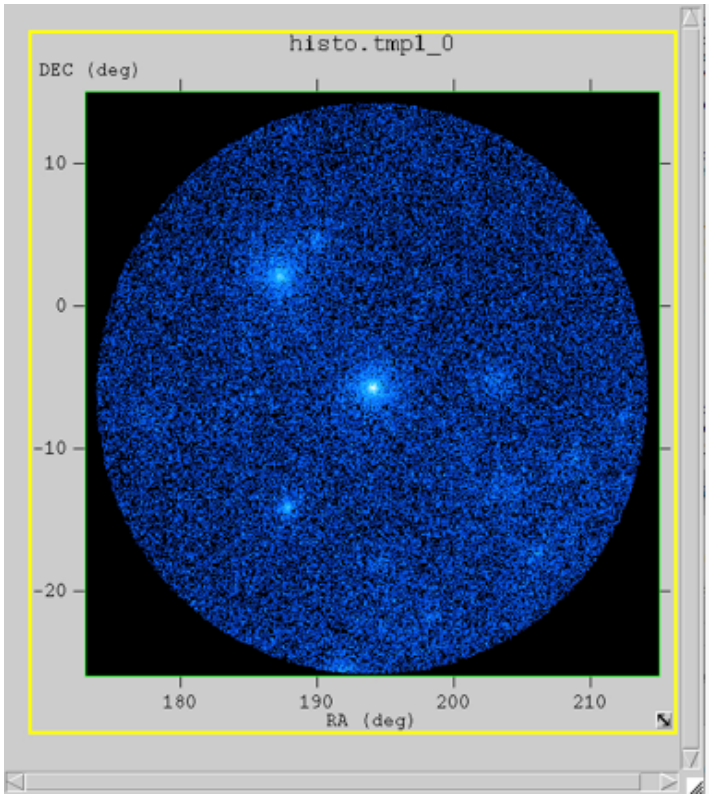


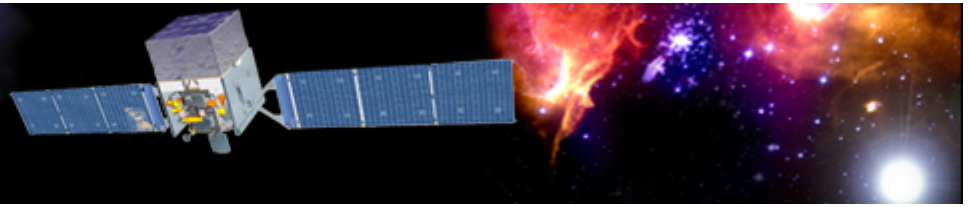
# Quick count maps

ds9 -bin factor 0.1 0.1 -cmap b -scale sqrt
3C279_region_filtered_gti.fits &




fv 3C279_region_filtered_gti.fits &





# Count maps

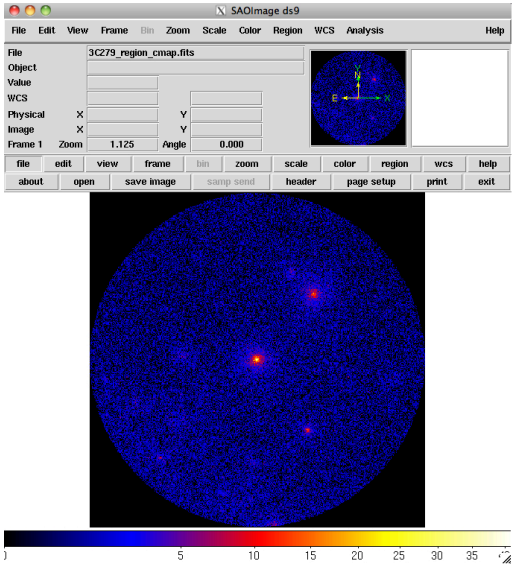
```
prompt> gtbin
This is gtbin version ScienceTools-v9r23p1-fssc-20110612
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [] CMAP
Event data file name[] 3C279_region_filtered_gti.fits
Output file name[] 3C279_region_cmap.fits
Spacecraft data file name[] NONE
Size of the X axis in pixels[] 400
Size of the Y axis in pixels[] 400
Image scale (in degrees/pixel)[] 0.1
Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [CEL]
First coordinate of image center in degrees (RA or galactic l)[] 193.98
Second coordinate of image center in degrees (DEC or galactic b)[] -5.82
Rotation angle of image axis, in degrees[0.]
Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN:[] AIT
```

No spacecraft file needed for count map

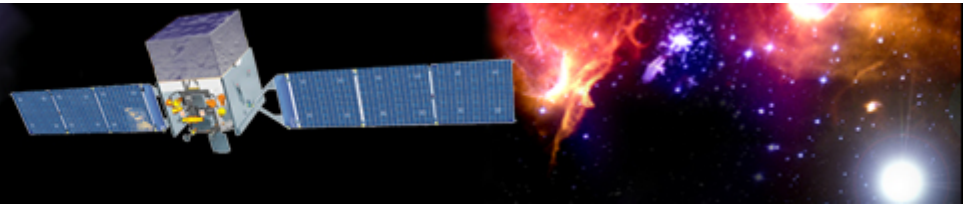
Here, ROI diameter / image scale = size of each axis

To view the entire region, match these values to the header values

AIT = Hammer-Aitoff (good for all-sky map)
see Calabretta & Greisen 2002, A&A, 395, 1077 (sect. 5 and 7.2)

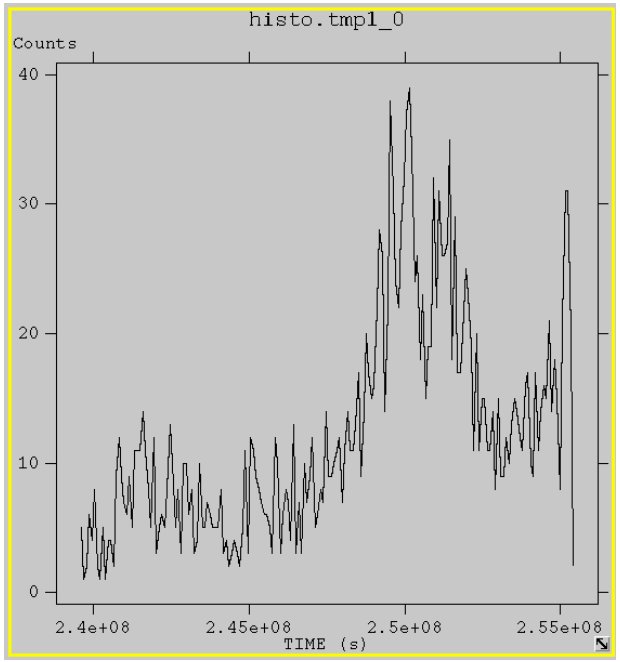



Comparing this to the images made with *fv* and *ds9*, the image is flipped along the x-axis. This is because the coordinate system keywords have been properly added to the image header and the Right Ascension coordinate actual increases right to left and not left to right.



# Quick light curve

```
[ddonato@gladio fermi_workshop]$ gtselect
Input FT1 file[] L1203211445197365007F88_PH00.fits
Output FT1 file[] 3C279_region_1deg.fits
RA for new search center (degrees) (0:360) [INDEF] 194.047
Dec for new search center (degrees) (-90:90) [INDEF] -5.78931
radius of new search region (degrees) (0:180) [INDEF] 1
start time (MET in s) (0:) [INDEF] 239557417
end time (MET in s) (0:) [INDEF] 255398400
lower energy limit (MeV) (0:) [100]
upper energy limit (MeV) (0:) [300000] 100000
maximum zenith angle value (degrees) (0:180) [180] 100
```



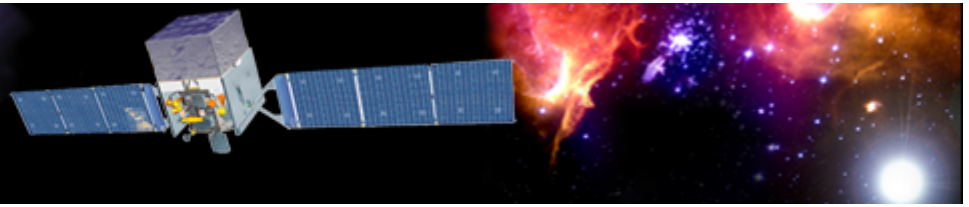

fv 3C279_region_1deg.fits &

Select “Hist” from extension 1 (EVENTS)

Select “Time” for the X-axis

Set Min, Max and Bin Size to something meaningful

Press “Make” to plot Counts vs Time (in MET)



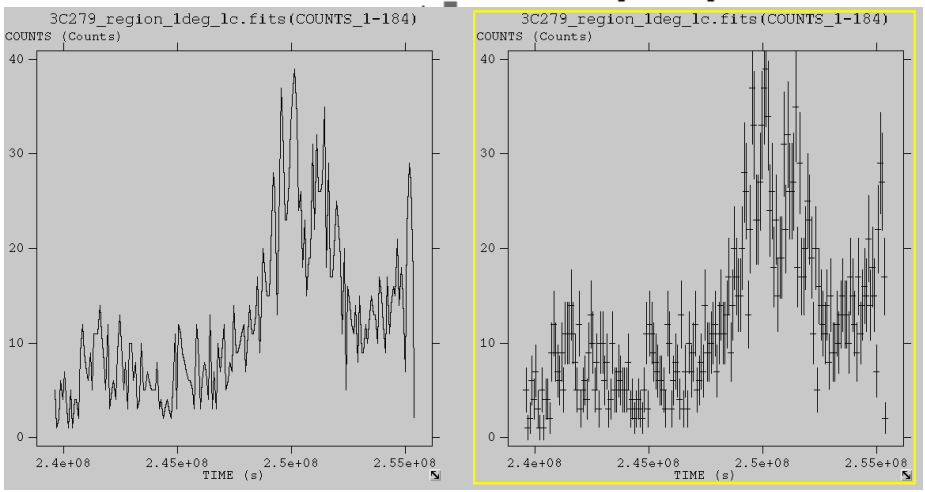
# Quick light curve

```
[ddonato@gladio fermi_workshop]$ gtmktime
Spacecraft data file[spacecraft.fits] L1203211445197365007F88_SC00.fits
Filter expression[DATA_QUAL==1 && LAT_CONFIG==1 && ABS(ROCK_ANGLE)<52]
Apply ROI-based zenith angle cut[yes]
Event data file[3C279_region_filtered.fits] 3C279_region_1deg.fits
Output event file name[3C279_region_filtered_gti.fits] 3C279_region_1deg_gti.fits

[ddonato@gladio fermi_workshop]$ gtbin
This is gtbin version ScienceTools-09-27-01
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2) [LC]
Event data file name[3C279_region_filtered_gti.fits] 3C279_region_1deg_gti.fits
Output file name[lc_3C279.fits] 3C279_region_1deg_lc.fits
Spacecraft data file name[spacecraft.fits] L1203211445197365007F88_SC00.fits
Algorithm for defining time bins (FILE|LIN|SNR) [LIN]
Start value for first time bin in MET[239558048] 239557417
Stop value for last time bin in MET[255380054] 255398400
Width of linearly uniform time bins in seconds[604800] 86400
```

Rename spacecraft file if it's easier

Times do not have to align to full data series (although here they are…)




fv 3C279_region_1deg.fits &

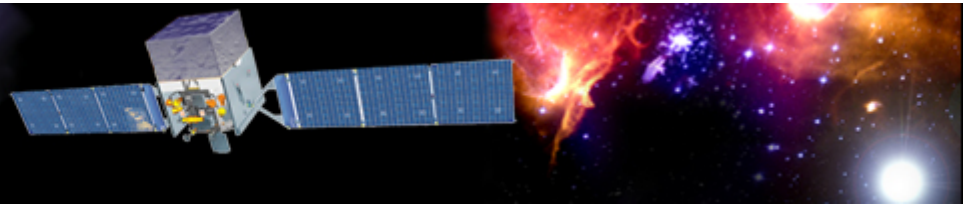
Select "Plot" from extension 1 (EVENTS)

Select "Time" and "X"

Select "Counts" and "Y"

Press "Plot"

Add errors : select "Timedel" for "X Error" and "Error" for "Y Error"



# Aperture Photometry

The light curve from gtbin must be exposure corrected using gtexposure (it adds the "Exposure" column to the fits file)

```
[ddonato@gladio fermi_workshop]$ gtexposure
Light curve file[lc_3C279.fits] 3C279_region_1deg_lc.fits
Spacecraft file[spacecraft.fits] L1203211445197365007F88_SC00.fits
Response functions[P7SOURCE_V6]
Source model XML file[none]
Photon index for spectral weighting[-2.1]
```

A more complicated (larger) region will require a source model

This is a good "default" spectral index for LAT sources

- To convert to rates, use fv or other tool (like ftcalc) to divide counts and errors by exposure

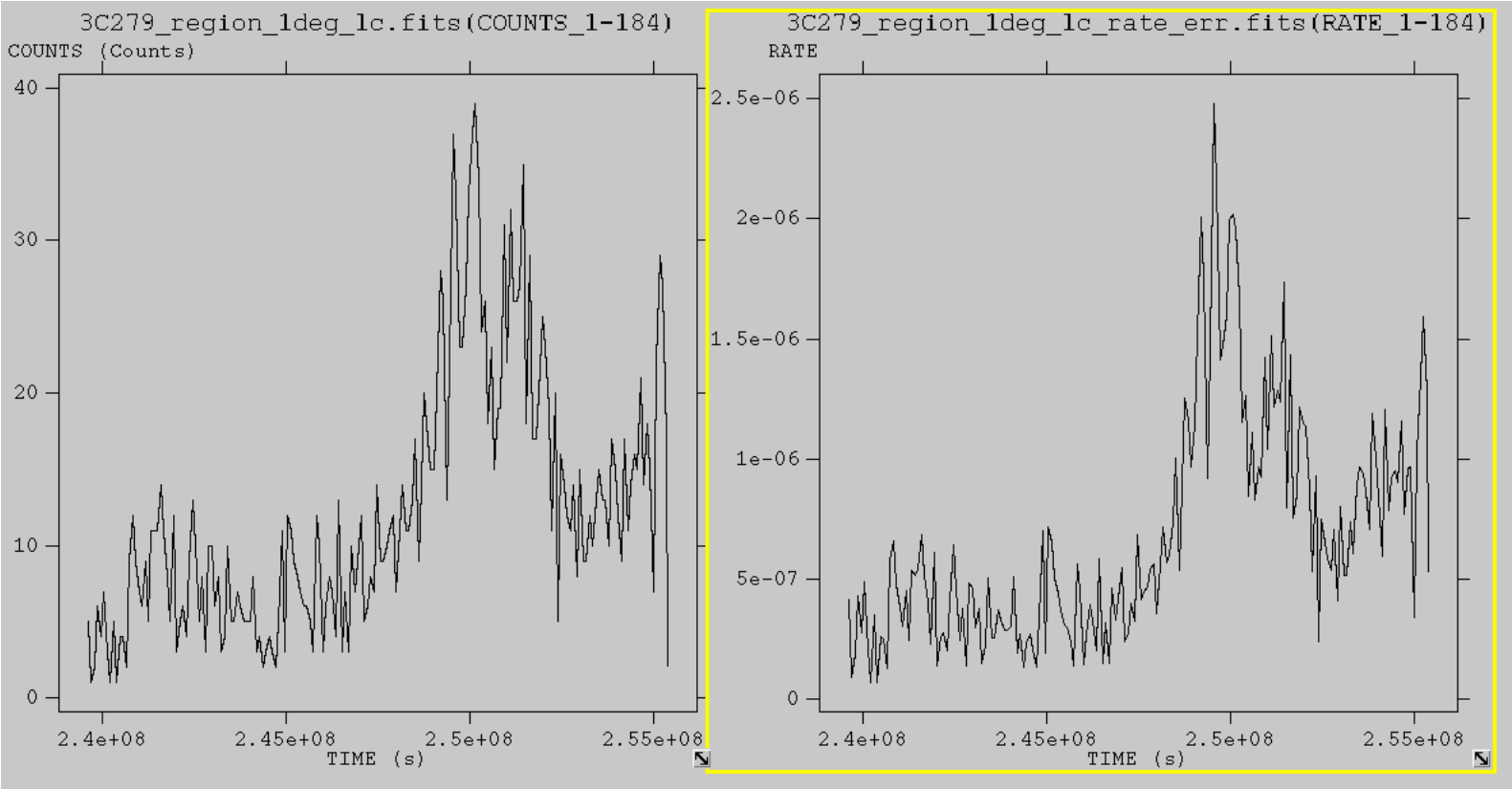
```
ftcalc 3C279_region_1deg_lc.fits 3C279_region_1deg_lc_rate.fits RATE 'counts/exposure'
ftcalc 3C279_region_1deg_lc_rate.fits 3C279_region_1deg_lc_rate_err.fits RATE_ERROR 'error/exposure'
```

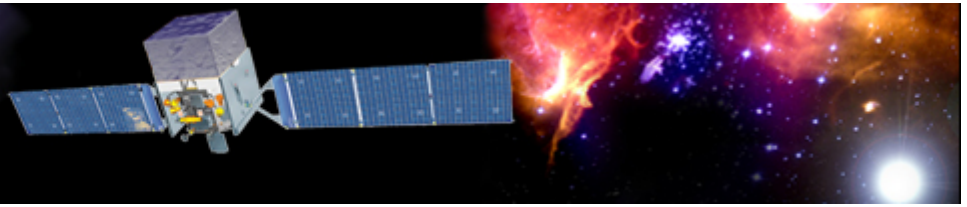
- Error bars in output are sqrt(counts)
  - In some instances (e.g., too few counts) this may be incorrect
  - Correcting this may be more complicated

# Aperture Photometry

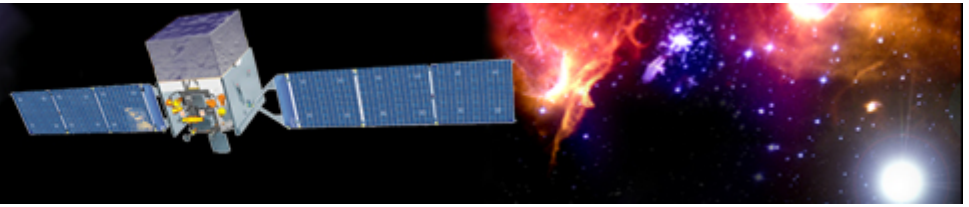
Non-corrected count light curve

Corrected count/rate light curve



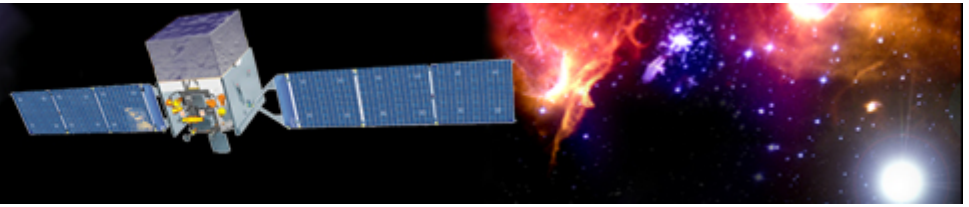


# End



# Barycentering

- If your source is sensitive to the motion of the Earth, you may wish to barycenter the events file to remove that effect
- gtbary is usually used to barycenter the events file for pulsar timing. But it can also be used for light curves
  - gtbary must be the last step of the analysis (after exposure calculation)
  - Spacecraft file must be longer than the events file (remember this when doing the gtselect step)
  - gtbary overwrites the time column with the barycentered (corrected) photon arrival times. It's wise to make a copy of your data file before running gtbary.



# Using Exposure Errors

- For some purposes, errors based on observed counts may not be correct
- Alternative is to use errors based on the exposure
  - Calculate the mean count rate
  - For each time bin, calculate the expected number of counts based on the exposure for that time bin
  - Take the square root of that predicted number of counts
  - Divide by the exposure to get the rate
  - The resulting error value is based only on the "quality" of each time bin
- References for error bars treatment:
  - Gehrels, 1986, ApJ, 303, 336
  - Kraft, Burrows, & Nousek, 1991, ApJ, 374, 344